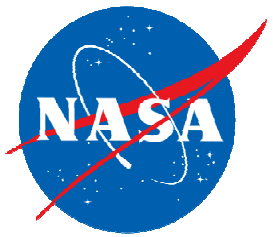
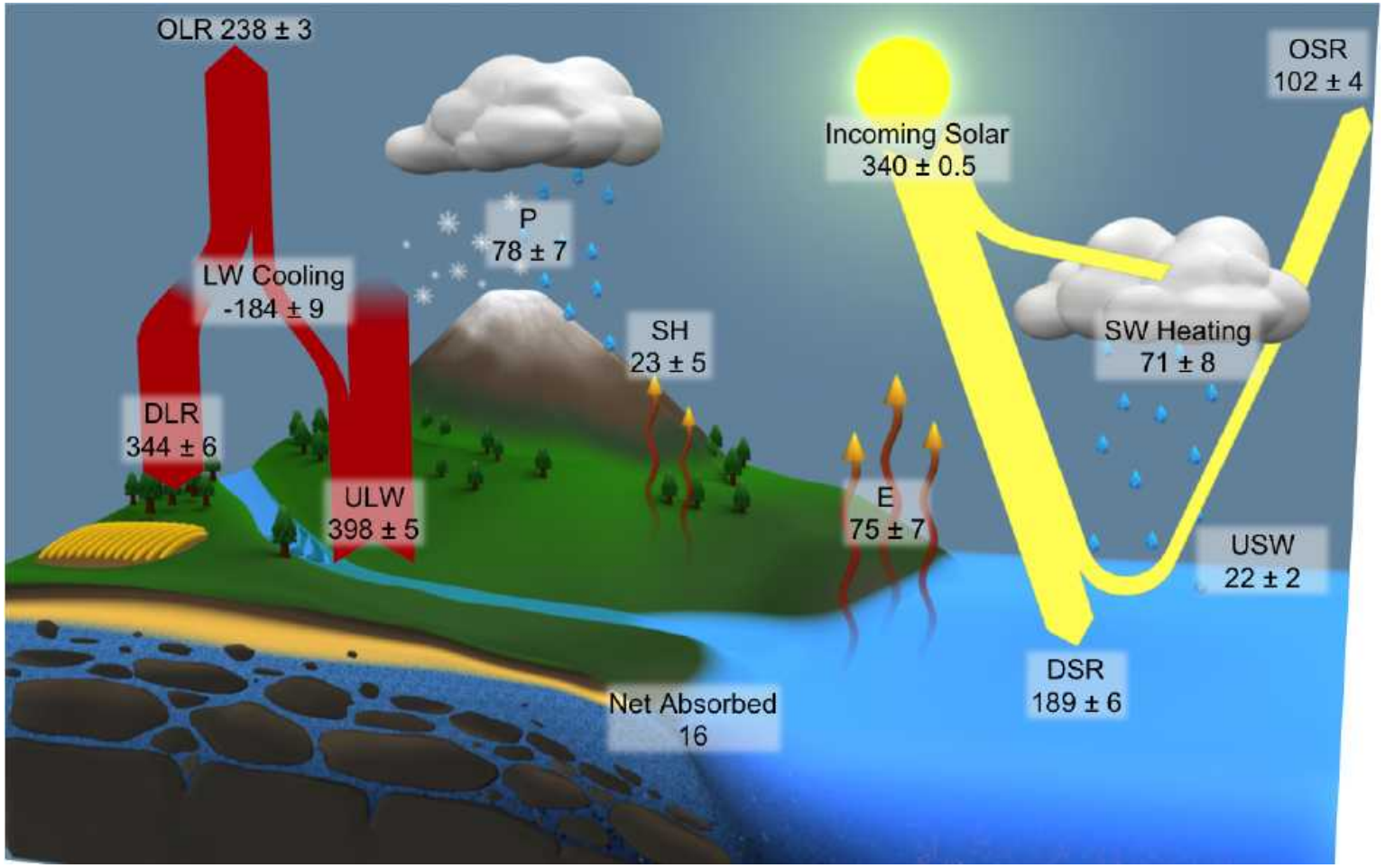
Temporal variability of atmospheric column energy balance residual

Seiji Kato[1], Norman G. Loeb[1], John Fasullo[2],
David A. Rutan[3], and Fred. G. Rose[3]

[1]NASA Langley Research Center
[2]National Center for Atmospheric Research
[3]Science System & Applications Inc.



Current status of satellite based surface energy balance residual in Wm^{-2}



L'Ecuyer et al. 2015 (J. Climate)

Surface: 344-398-23-75+189-22=15 Wm^{-2} (depending on data sets used)

Ocean heating rate: 0.53 to 0.75 Wm^{-2} (Lyman et al. 2010 Nature)

0.4 - 0.6 Wm-2 in 0 to 2000 m layer (Roemmich et al. 2015)

0.64+-0.44 Wm-2 for the entire column (Llovel et al. 2014)

Objective of this study

- Where do large energy balance residuals exist?
- Do newer versions of data products have a smaller energy balance residual?
  - Top-of-atmosphere and surface radiation products (EBAF-TOA and –surface) were revised from Edition 2.8 to Edition 4.0
  - Precipitation data product (Global Precipitation Climatology Project) was revised from Version 2.2 to 2.3.
  - Dynamical energy transport computed from ERA-Interim is revised.
  - Seaflux data product was extended through December 2016.
- How do the energy balance residual vary temporally and spatially?
- What is needed to reduce the residual.

Regions with a large energy imbalance

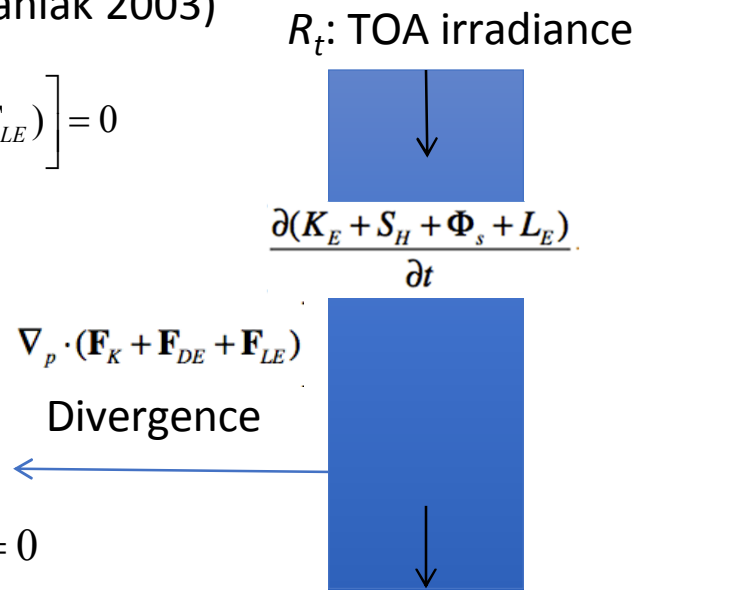
Atmospheric energy balance (Trenberth and Stepaniak 2003)

$$-\left[\frac{\partial(K_E + S_H + \Phi_s + L_E)}{\partial t} - (R_T - R_s) + H_s + LE + \nabla_p \cdot (\mathbf{F}_K + \mathbf{F}_{DE} + \mathbf{F}_{LE})\right] = 0$$

Water mass balance

$$-\left[\frac{\partial L_E}{\partial t} + LP + LE + \nabla_p \cdot \mathbf{F}_{LE}\right] = 0$$

$$-\frac{\partial(K_E + S_H + \Phi_s)}{\partial t} - \nabla_p \cdot (\mathbf{F}_K + \mathbf{F}_{DE}) + (R_T - R_s) + LP - H_s = 0$$



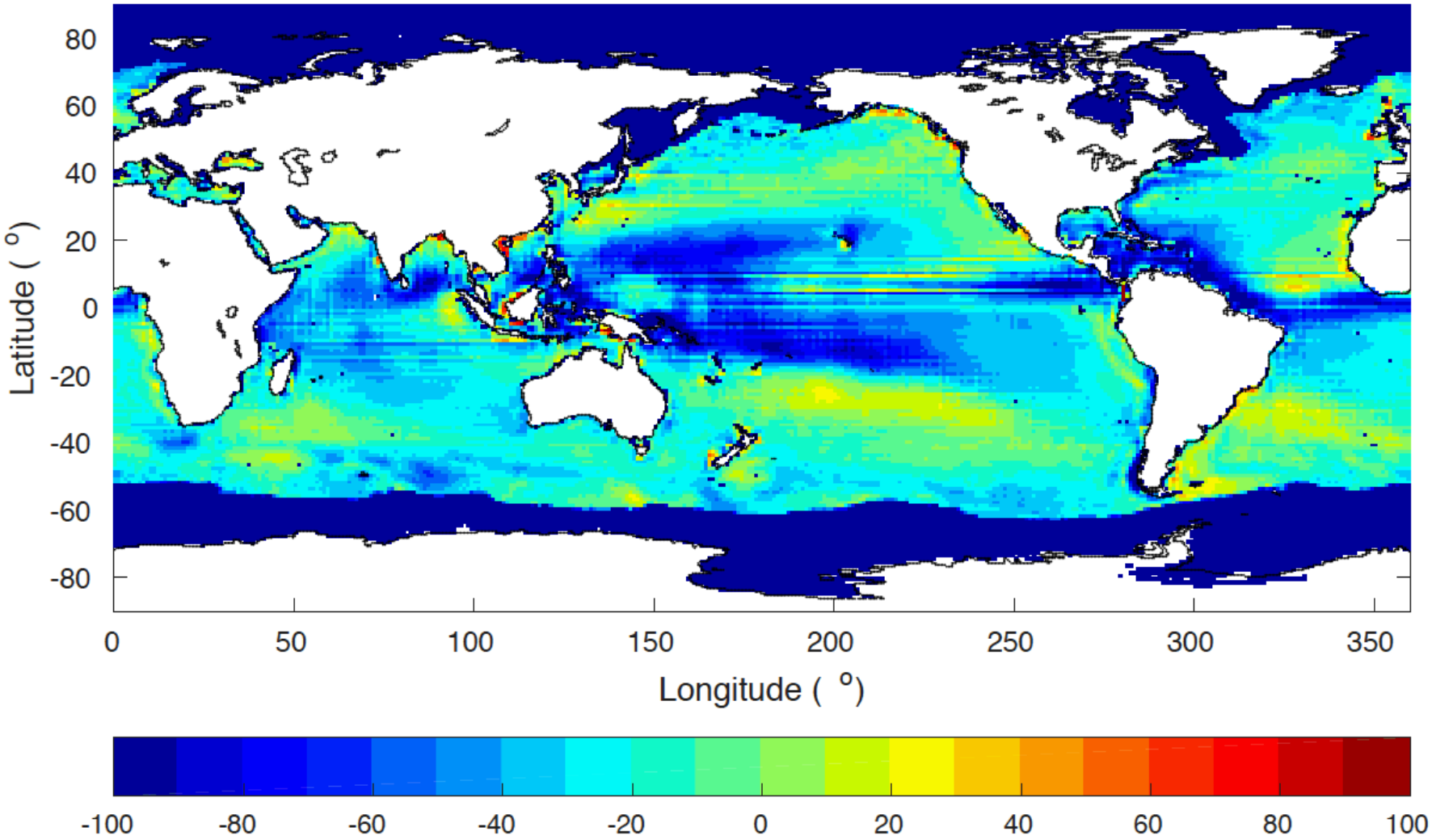
- Kinetic energy + dry static energy tendency
- Kinetic energy divergence
+ atmospheric net irradiance
+ precipitation × (latent heat of vaporization)
- Surface sensible heat flux (positive downward)

Dry static energy = sensible heat flux + potential energy
Neglecting water phase change (the error in the global mean is about 0.8 Wm^{-2})

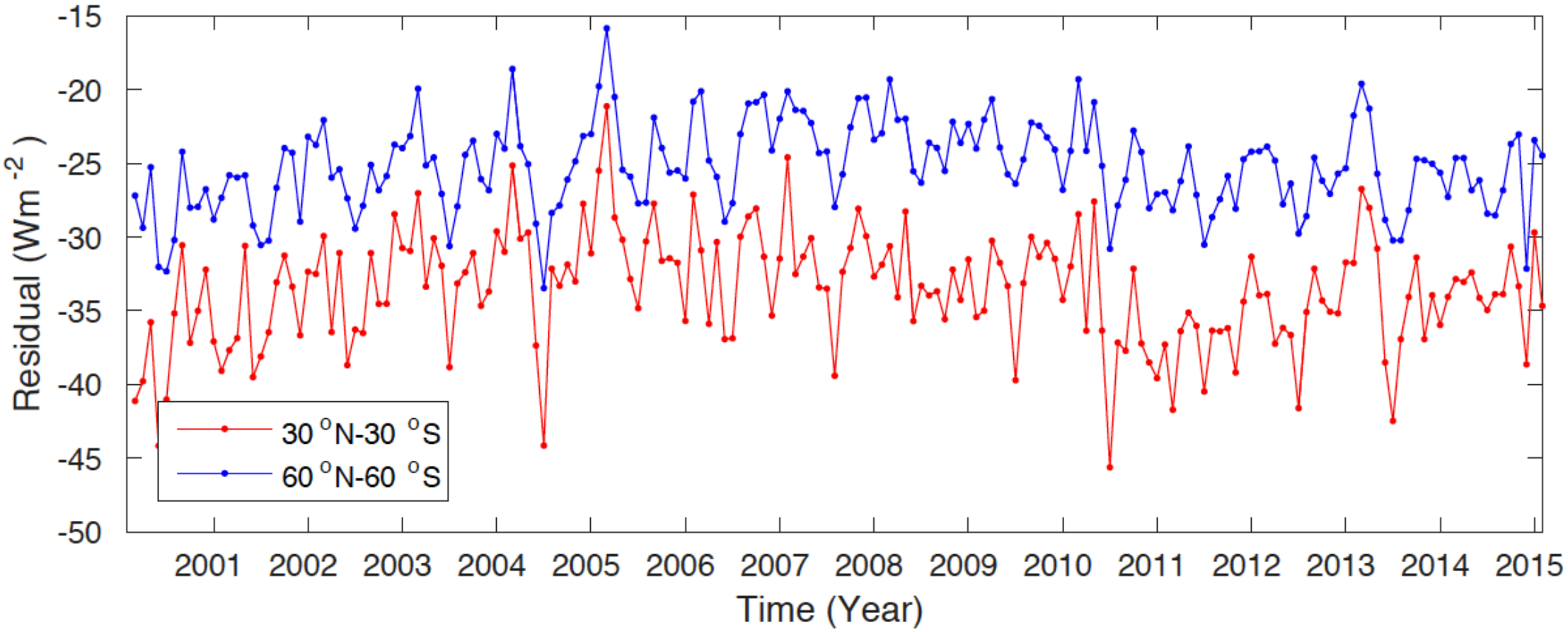
Testing atmospheric energy balance using observations Data source (March 2000 through Dec. 2016)

- Atmospheric net irradiance: EBAF-TOA and EBAF-surface (Ed 4.0, Loeb et al. 2018; Kato et al. 2018)
- Precipitation: GPCP (V2.3, Huffman et al. 1997; Adler et al. 2012)
- Surface sensible and latent heat flux: SeaFlux (Jan 2000 through Dec. 2016, Clayson and Bogdanoff 2014).
- Divergence of dry static energy: ERAI.DSEDIV (Fasullo et al. 2018)
- Divergence of kinetic energy: ERAI.KEDIV
- Divergence of latent energy: ERAI.LEDIV
- Total energy tendency: ERAI.TETEN
- Latent energy tendency: ERAI.LETEN

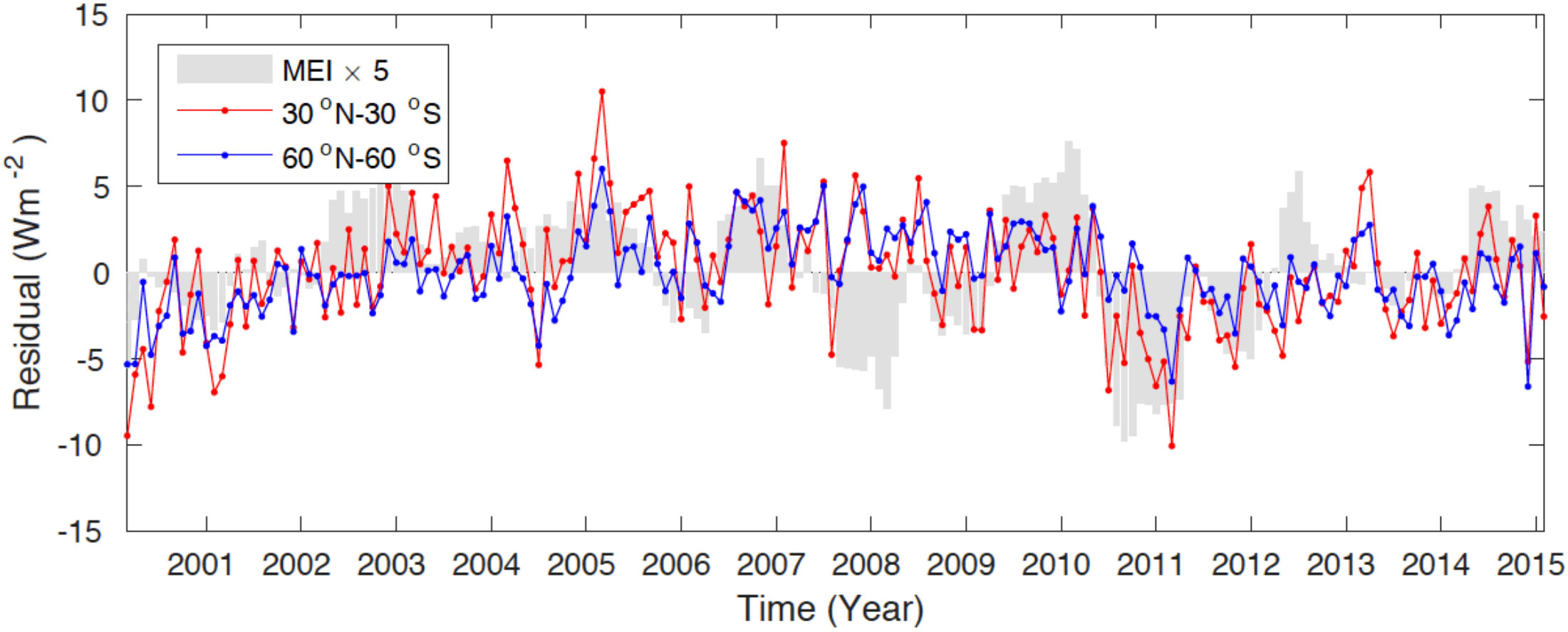
Global maps of residual



Time series of residual

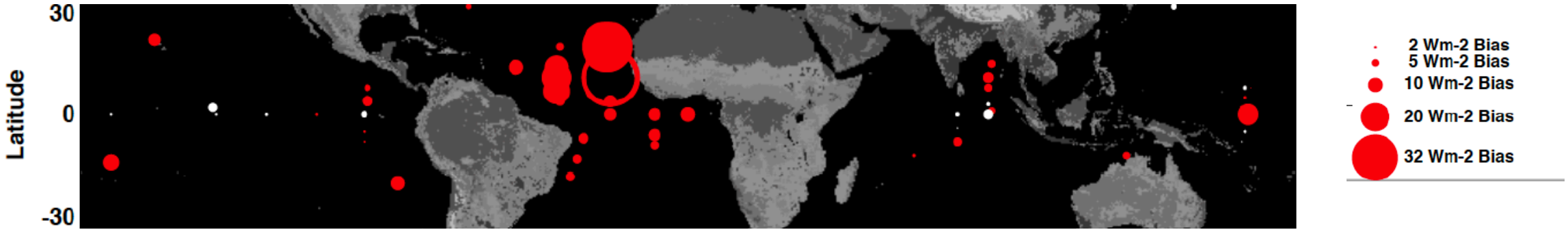


Anomaly time series of energy budget balance residual



Surface downward irradiance validation

Downward Shortwave irradiance



Downward longwave irradiance

Thoughts on what can be done in the future

- Investigate regional (tropics) energy balance.
- Investigate the effect of temperature dependent latent heat of vaporization (Mayer et al. 2018).